

For presentation as an invited talk in the “Gas and Process Analysis for Industrial Applications” session at the AVS 62nd International Symposium & Exhibition, October 18-23, 2015, San Jose, CA.

The Deployment of a Commercial RGA to the International Space Station

Matt Kowitt, Stanford Research Systems

Doug Hawk, Orbital-ATK

Dino Rossetti, Conceptual Analytics

Mike Woronowicz, Stinger Ghaffarian Technologies

ABSTRACT

The International Space Station (ISS) uses ammonia as a medium for heat transport in its Active Thermal Control System. Over time, there have been intermittent component failures and leaks in the ammonia cooling loop. One specific challenge in dealing with an ammonia leak on the exterior of the ISS is determining the exact location from which ammonia is escaping before addressing the problem.

Together, researchers and engineers from Stanford Research Systems (SRS) and NASA’s Johnson Space Center and Goddard Space Flight Center have adapted a commercial off-the-shelf (COTS) residual gas analyzer (RGA) for repackaging and operation outside the ISS as a core component in the ISS Robotic External Leak Locator, a technology demonstration payload currently scheduled for launch during 2015.

The packaging and adaptation of the COTS RGA to the Leak Locator will be discussed. The collaborative process of adapting a commercial instrument for spaceflight will also be reviewed, including the build-up of the flight units. Measurements from a full-scale thermal vacuum test will also be presented demonstrating the absolute and directional sensitivity of the RGA.



The Deployment of a Commercial RGA to the International Space Station

Matt Kowitt¹, Doug Hawk², Dino Rossetti³, Michael Woronowicz⁴

(1) Stanford Research Systems; (2) Orbital-ATK; (3) Conceptual
Analytics; (4) SGT Inc.

Wednesday, 21 October 2015

Outline

1. The International Space Station
 - a. overview
 - b. cooling systems
2. Residual Gas Analyzers
3. Conceptual overview of project
4. Adapting a “COTS” RGA for flight
5. Performance tests
6. Plans for the future, and lessons learned



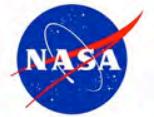
The International Space Station



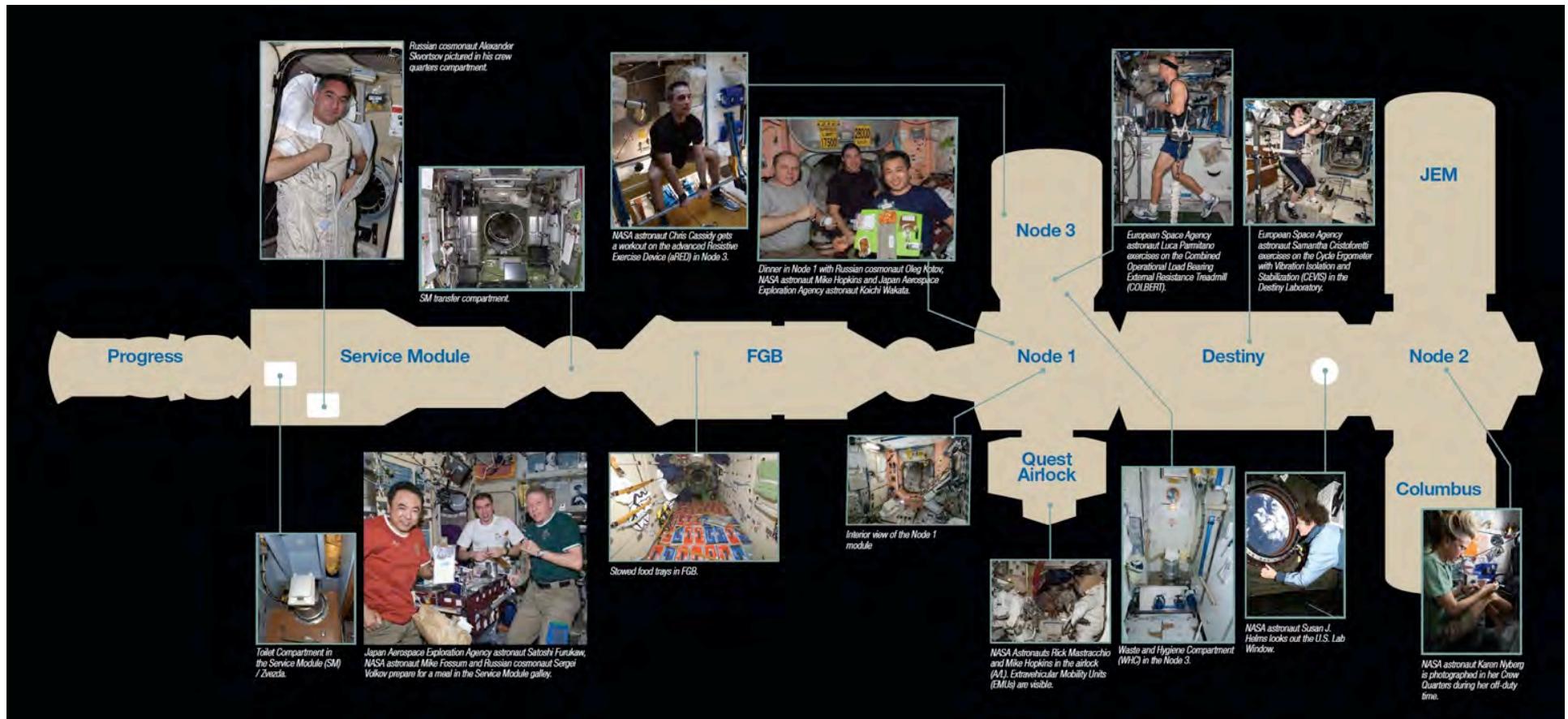


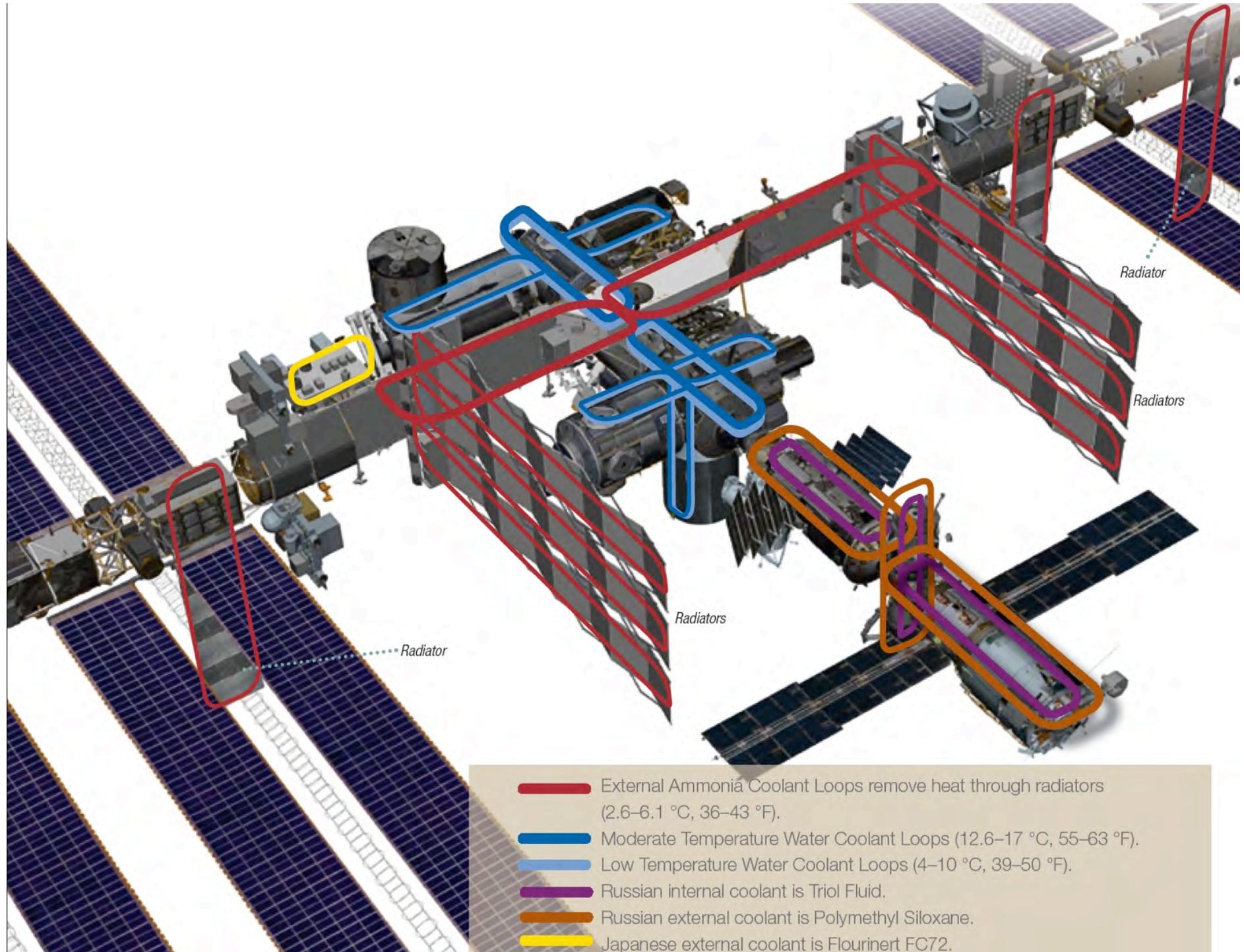
The ISS is BIG

National Aeronautics and Space Administration



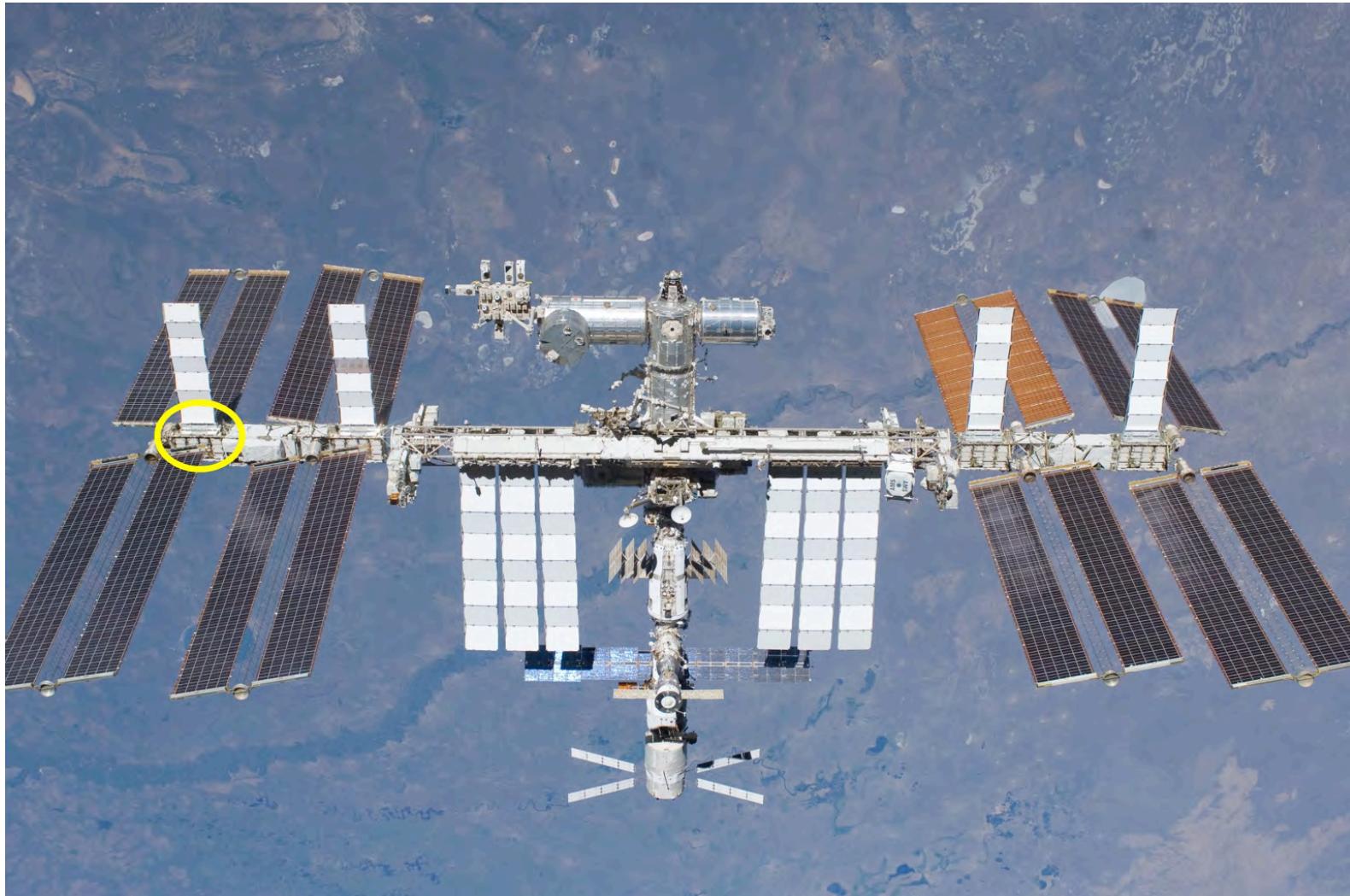
Where people live: ISS habitation modules



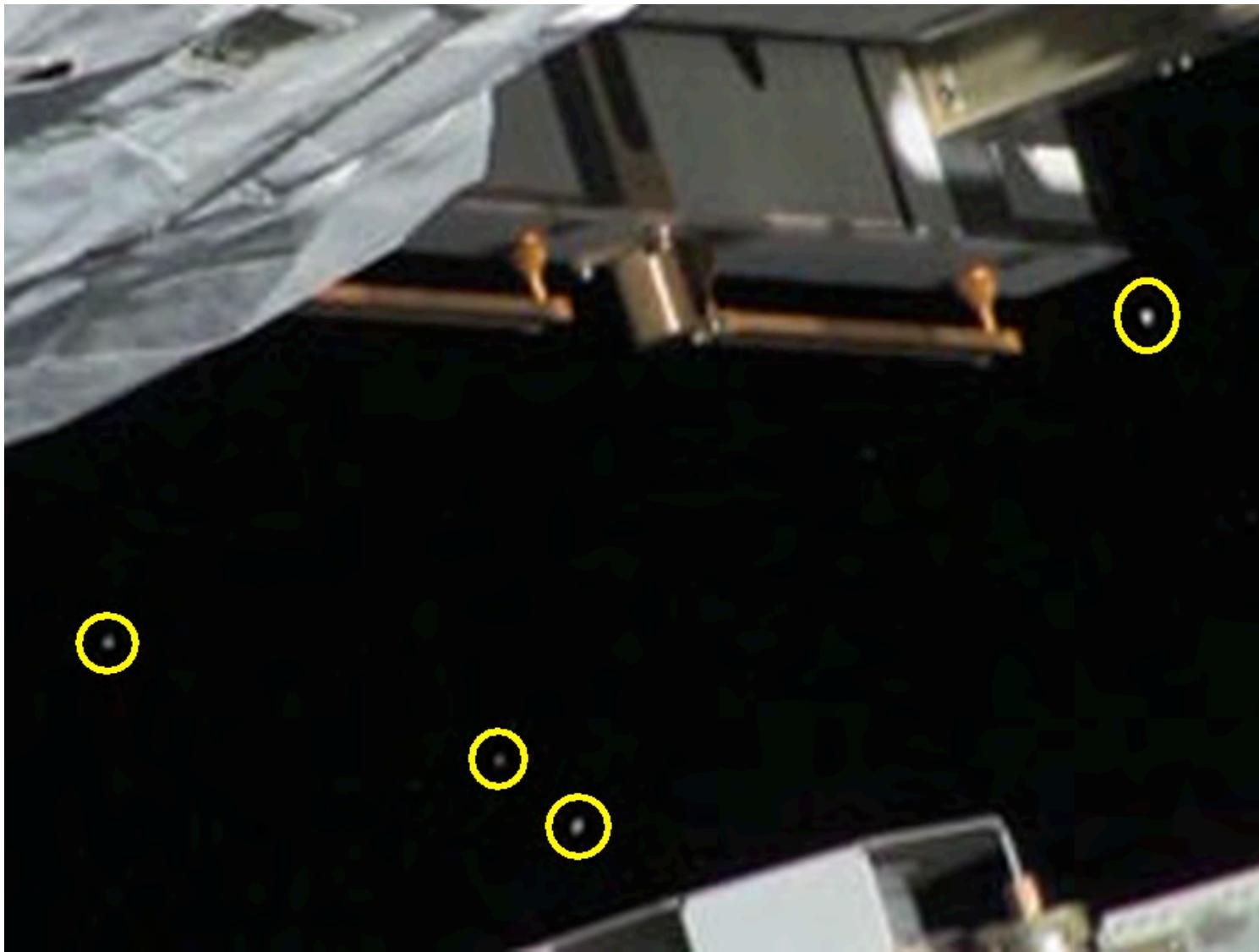




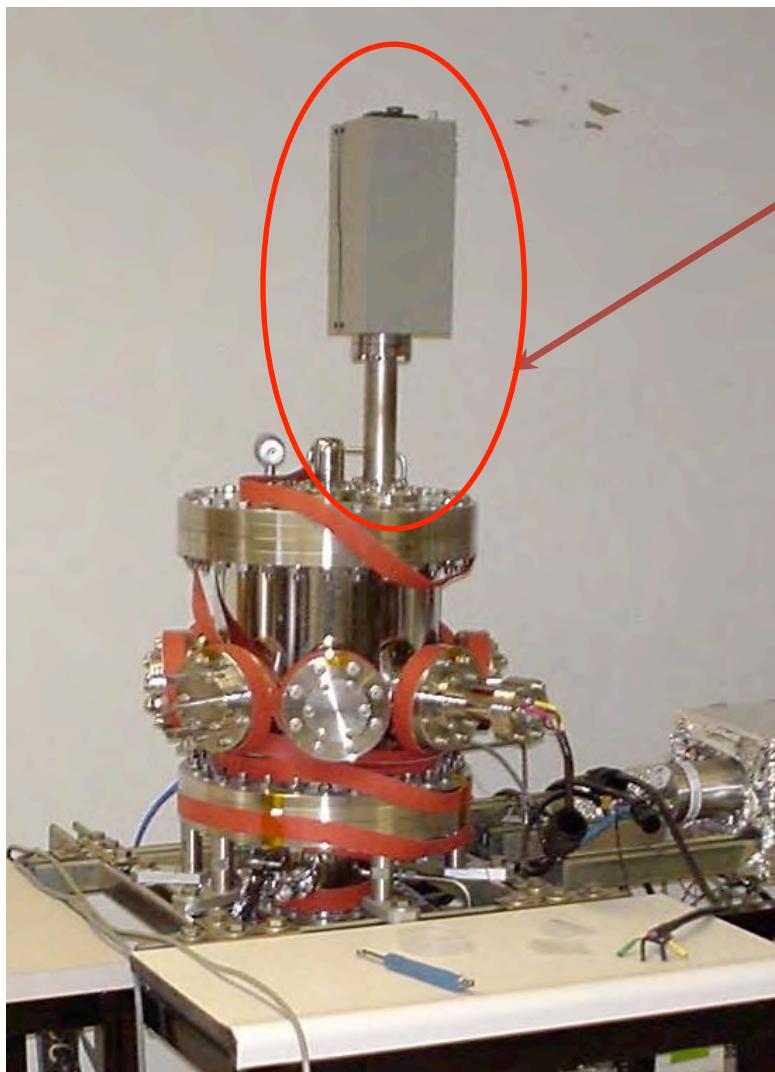
ISS: 2013 Ammonia Leak



Ammonia leak visually located



RGA: a *very* brief overview



RGA = Residual Gas Analyzer

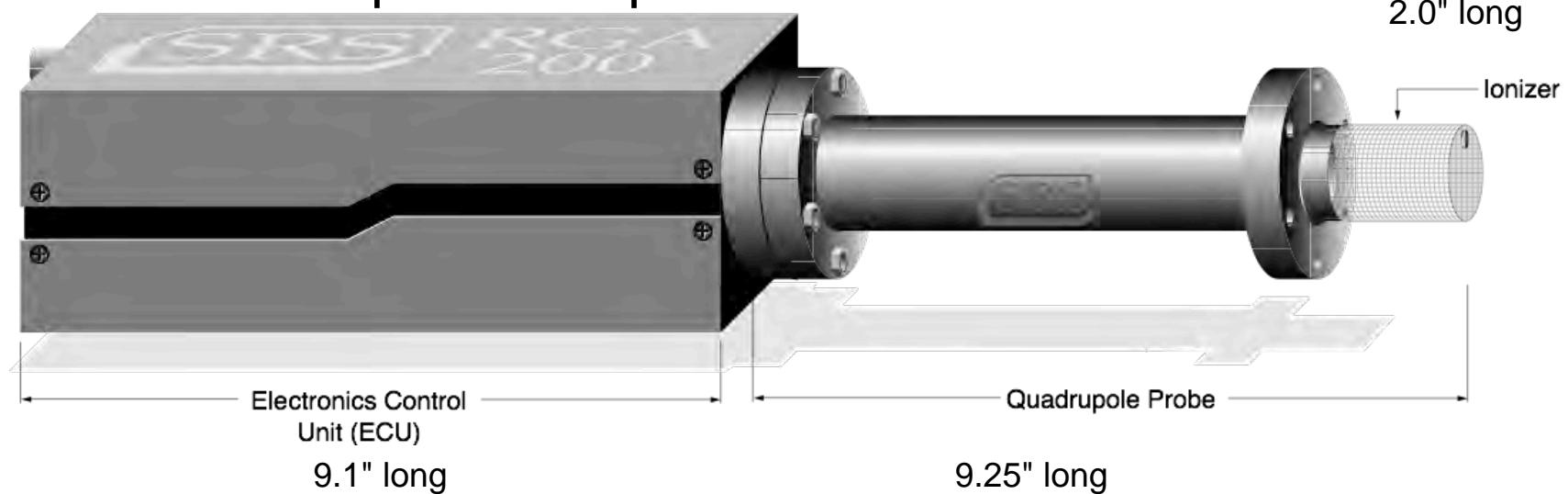
- a small mass spectrometer
- mated to a vacuum system
- analyzes the gases inside the vacuum chamber



The SRS RGA is a mass spectrometer consisting of a **quadrupole probe** and an **electronics control unit (ECU)**.

The probe mounts directly on the vacuum chamber.

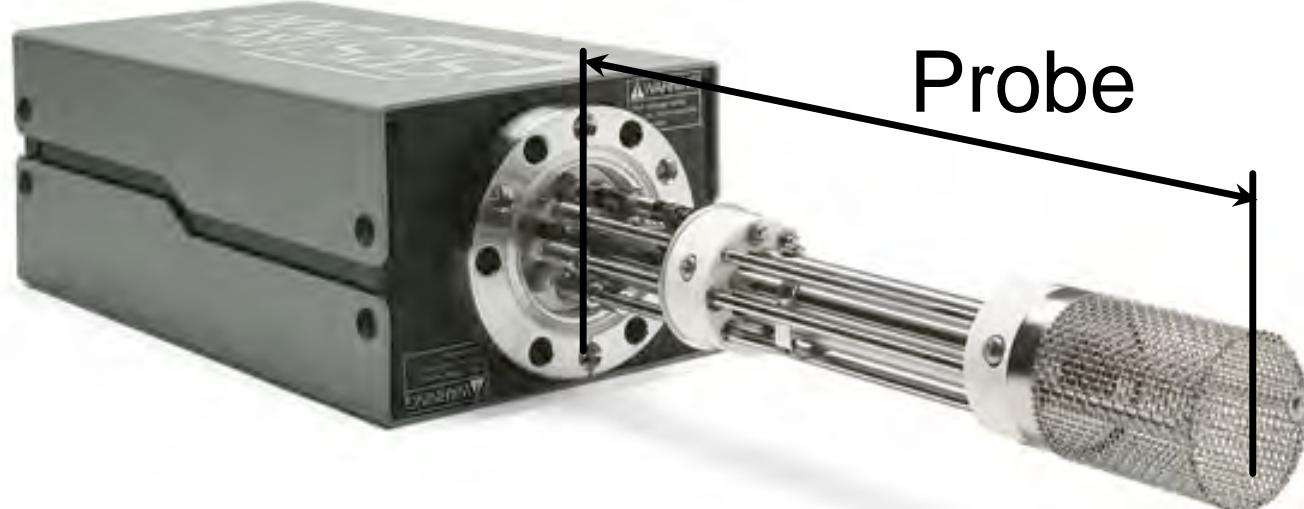
The ECU mounts on the probe and contains all the electronics required to operate the instrument.



Quadrupole Probe



gas molecules (analyte) are ionized
separated based on their mass/charge
detected as an ion current

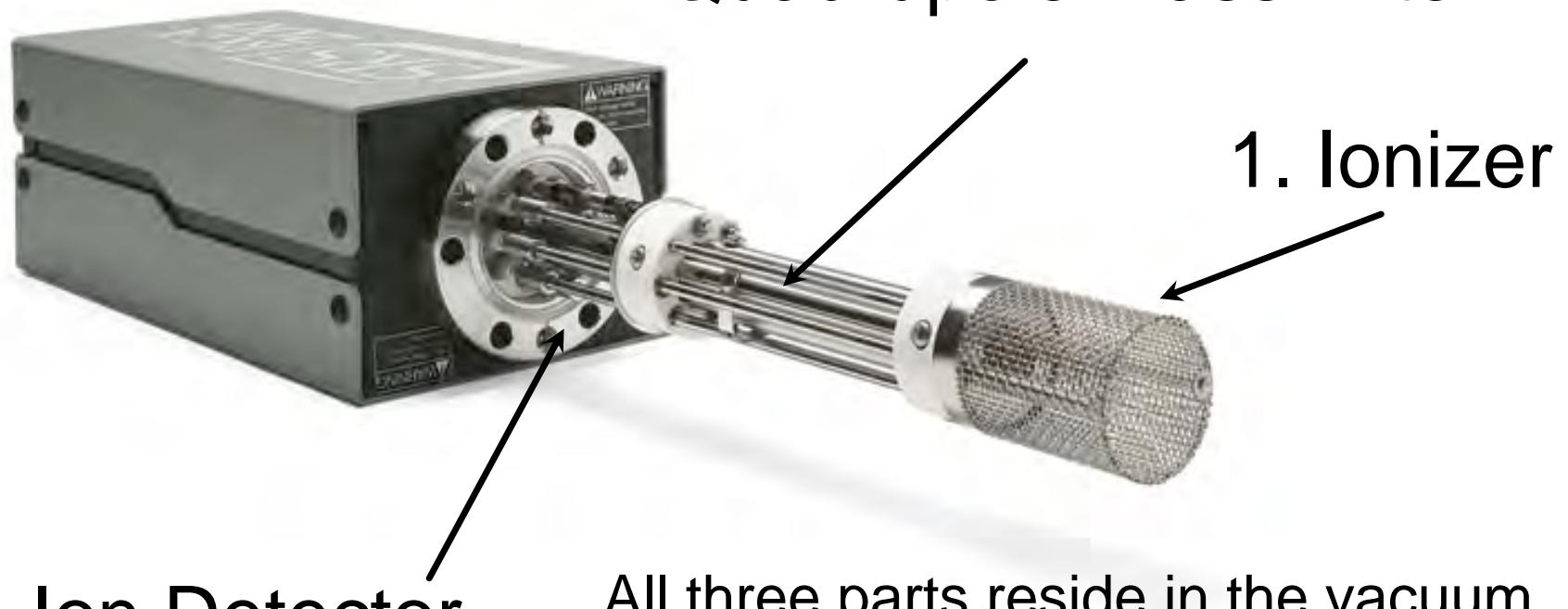


Probe Components



The probe consists of three parts:

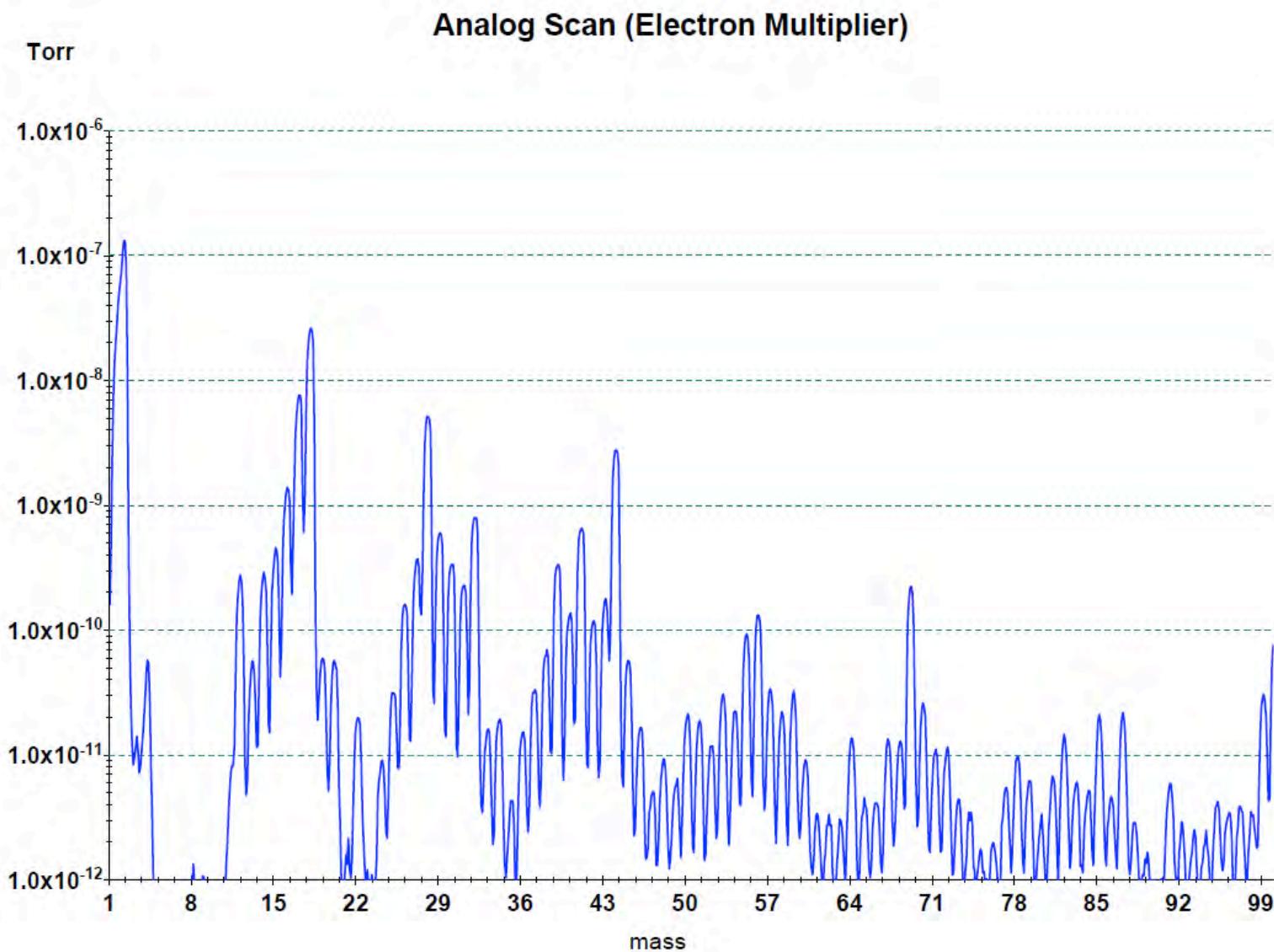
2. Quadrupole Mass Filter



3. Ion Detector

All three parts reside in the vacuum space where the gas analysis measurements are made.

RGA: typical data





About the RGA100

- based on compact quadrupole mass spec
- operates from 10^{-4} Torr to UVH
- mass resolution < 0.5 amu
- minimum detectable partial pressure:
 - 5×10^{-11} Torr (Faraday Cup detector)
 - 5×10^{-14} Torr (Electron Multiplier detector—option)
- probe size: 8.75" × 2.75" CF flange
- electronics size: 9.1"×4.1"×3.1"
- power: 24 VDC @ 2.5 A max (standard)
- interface: RS-232, 28.8kbaud fixed

Concept for ISS flight instrument



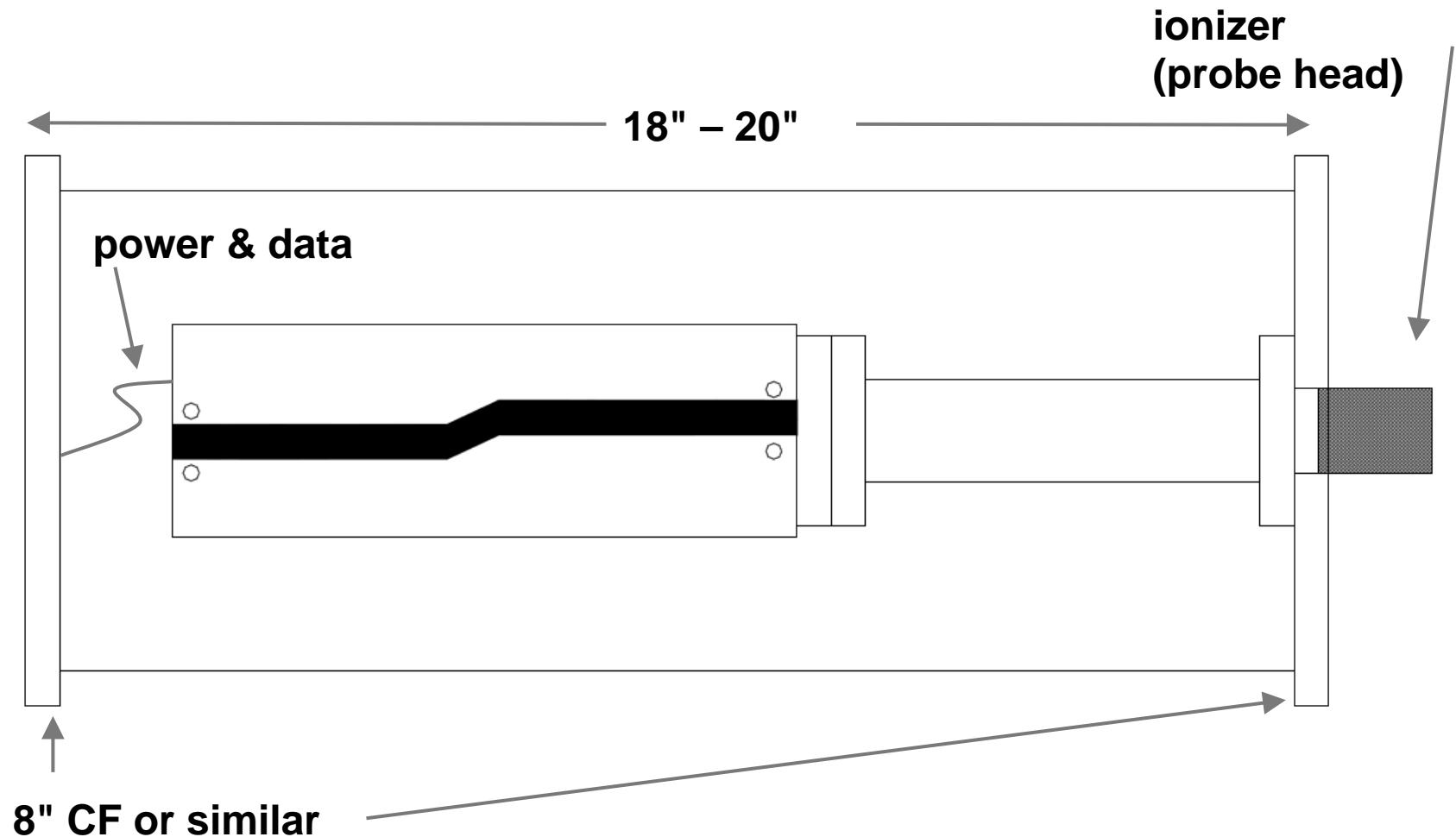
- Seek to adapt an RGA as mass-selective sensor to help locate future ammonia leaks
- Classical (terrestrial) use: Probe inside vacuum chamber, ECU out in lab
- Flight concept:
 - ECU in (pressure) chamber
 - Probe out in space
- Project's official name:
ISS Robotic External Ammonia Leak Locator

Brief aside: SRS is *not* an aerospace firm

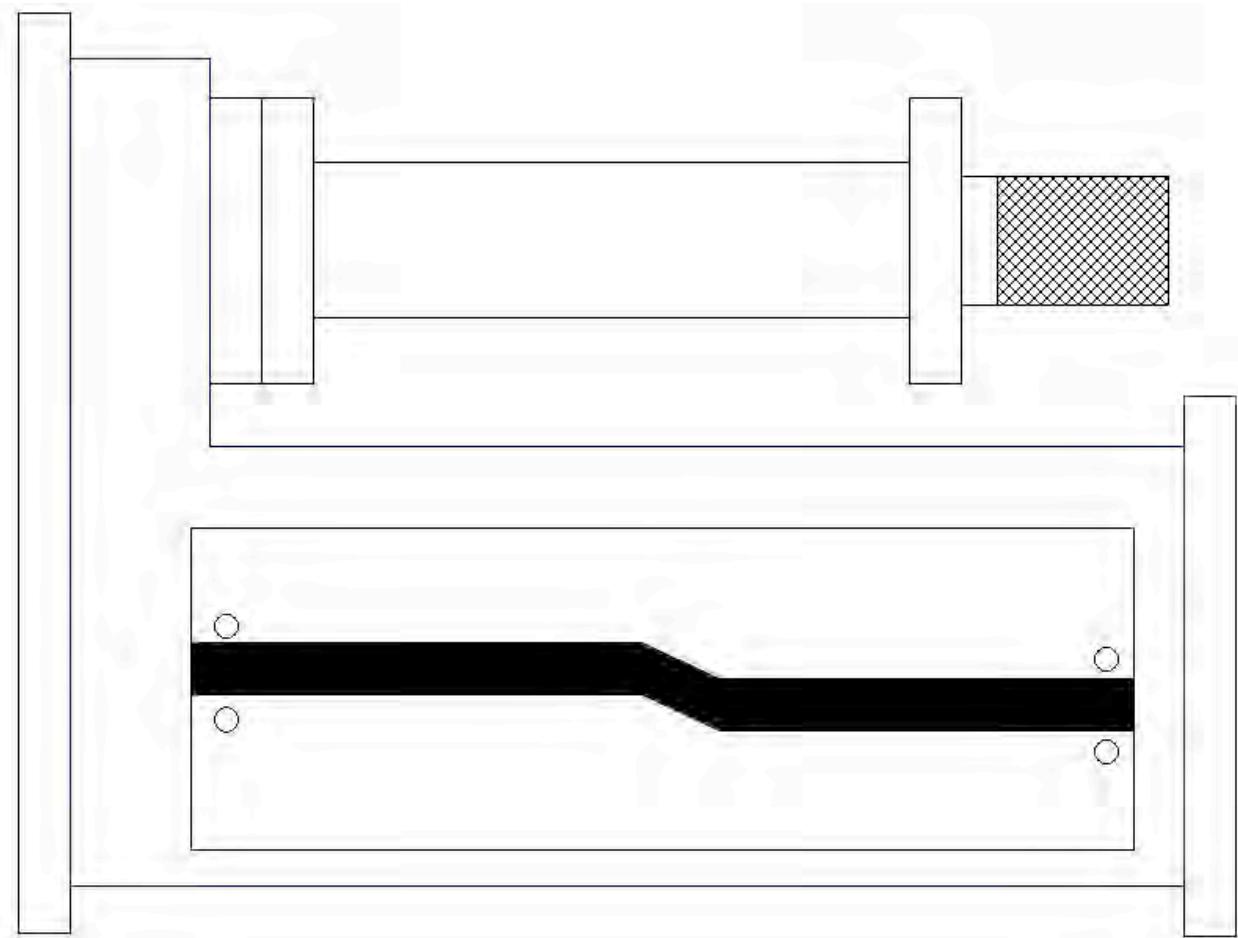


- Long experience with our COTS RGA
 - COTS = Commercial Off-the-Shelf
 - good performance
 - established field reliability over 20 years
- Clean demarcation of responsibility
 - SRS: builds the (modified) RGA
 - NASA: builds housing, full testing, flight qualification
 - Collaborate: define mods, review test plans

Initial concept



make it fit: “Folded” geometry *(modification from “COTS”)*



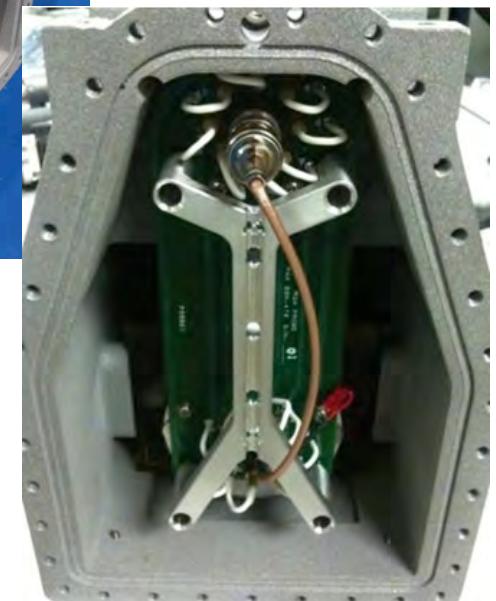
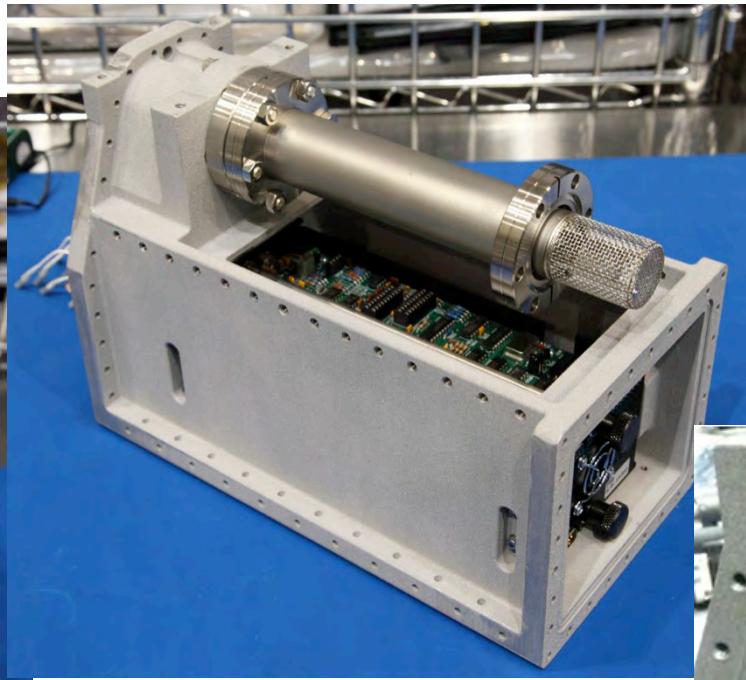
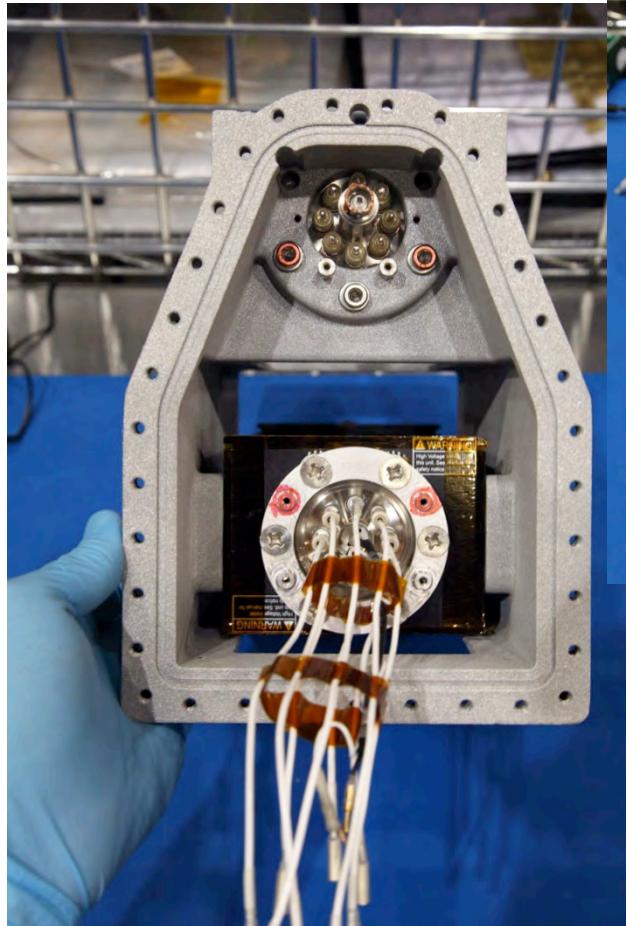


Project flow

- Proof of concept
- Iterate solutions to “folded” configuration
- (NASA designed) “Calibration & Ship Stand”
 - *non*-flight housing—built by 3D printing
 - RGA’s assembled into Cal/Ship Stands at SRS
 - Build multiple flight candidate RGA’s
- NASA tests RGA’s in the Cal/Ship stands
 - Select flight candidate (and rank spares)
- Repackage at NASA into Flight housing



Early prototypes...



Engineering Challenge: Probe / ECU Interconnect



- Requirements:

- Compact
- Insensitive to vibrations
- HV compatible with ultra-low leakage current
- Low capacitance / loss tangent for RF

- No single solution

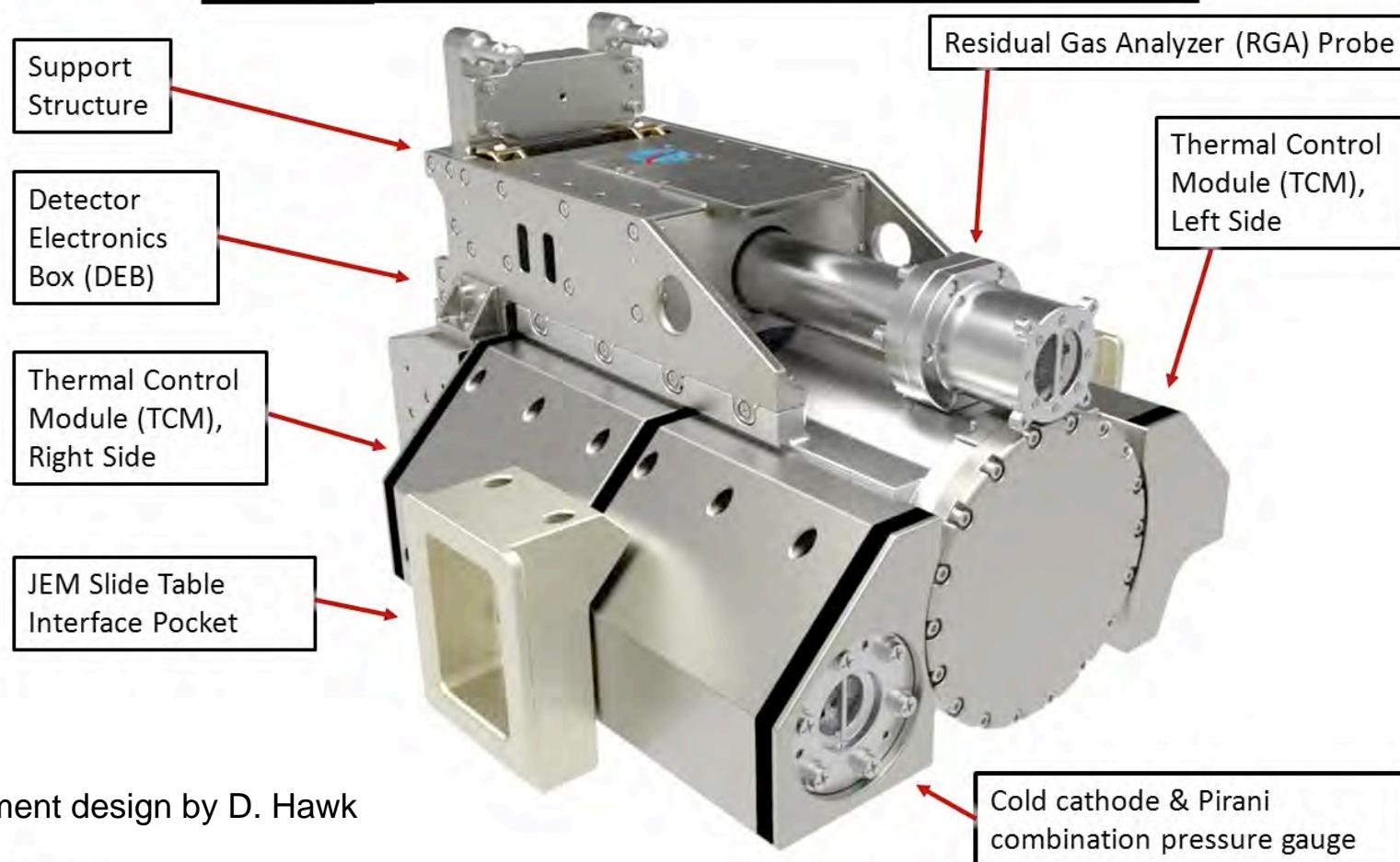
- Final design:

- synthesizes competing requirements
- performance tests prove out the results

Flight Configuration



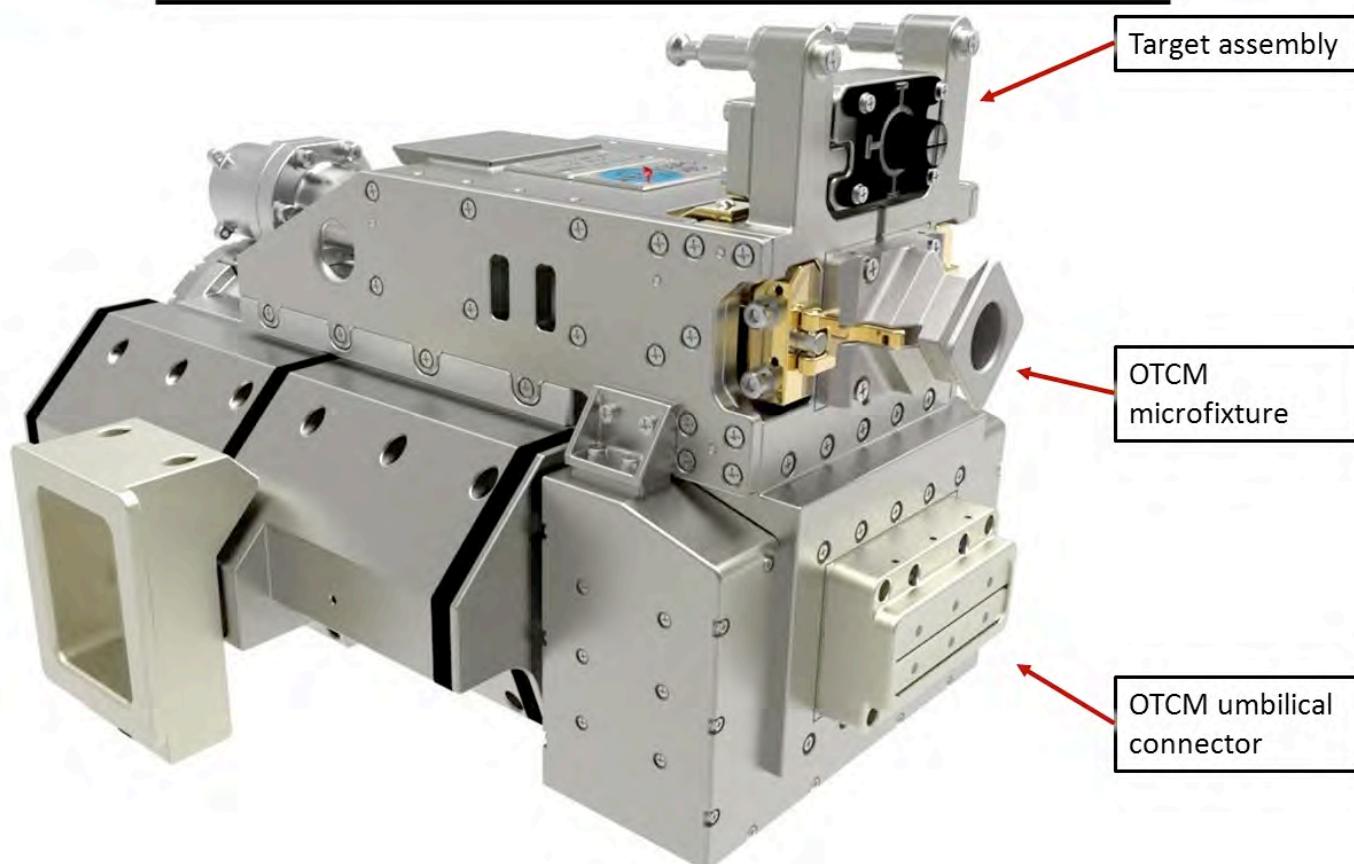
Design Details – overview



Flight Configuration, cont'd



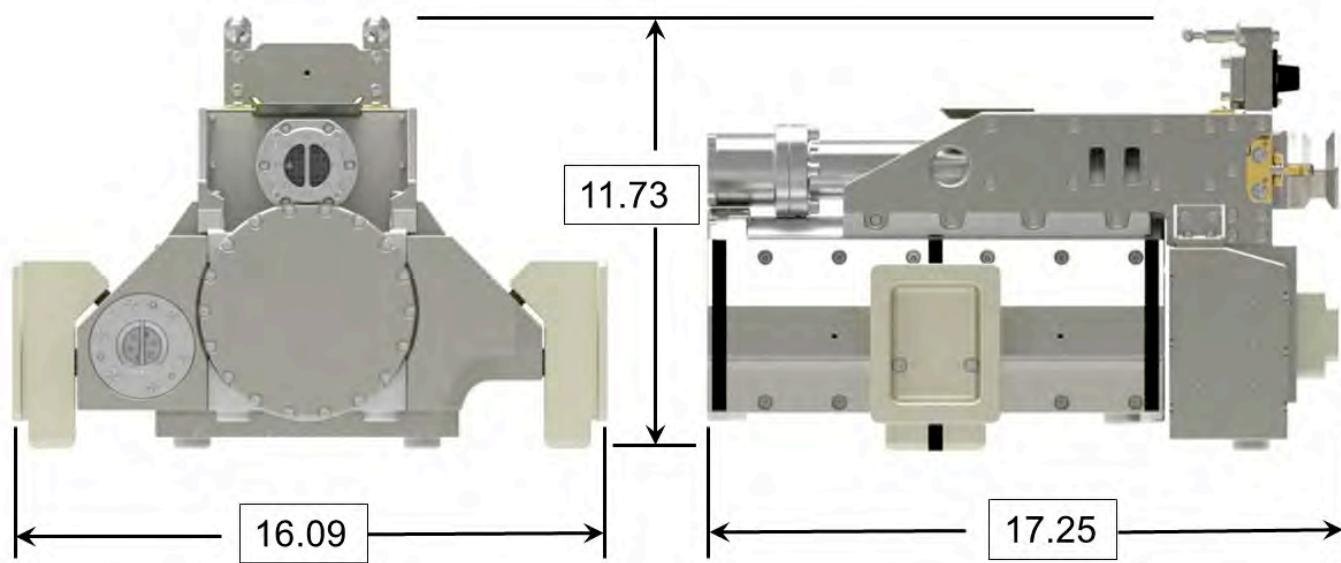
Design Details – overview (cont.)



Flight Configuration, dimensions

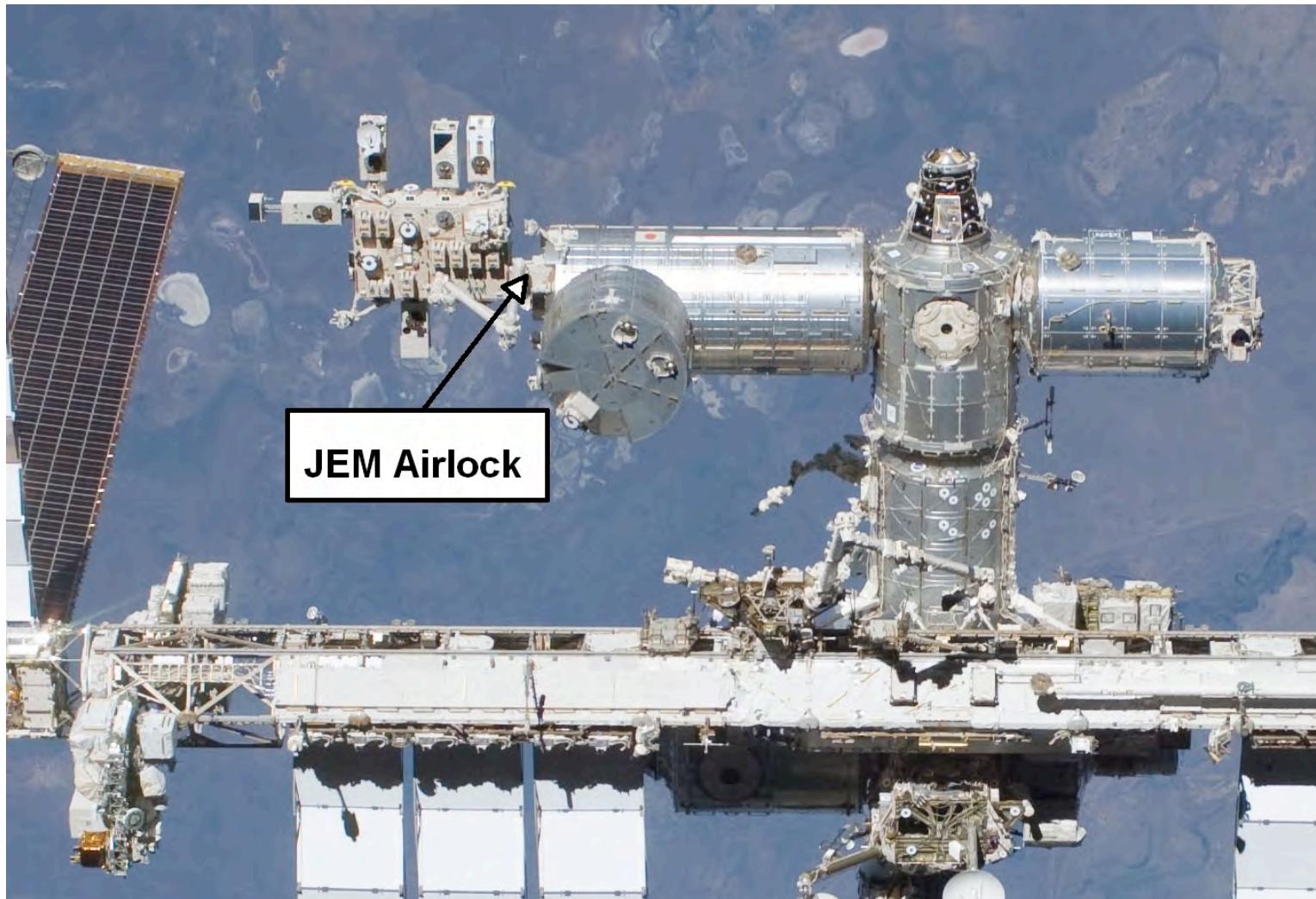


Overall Dimensions



inches

The JEM Airlock (the door to the outside...)

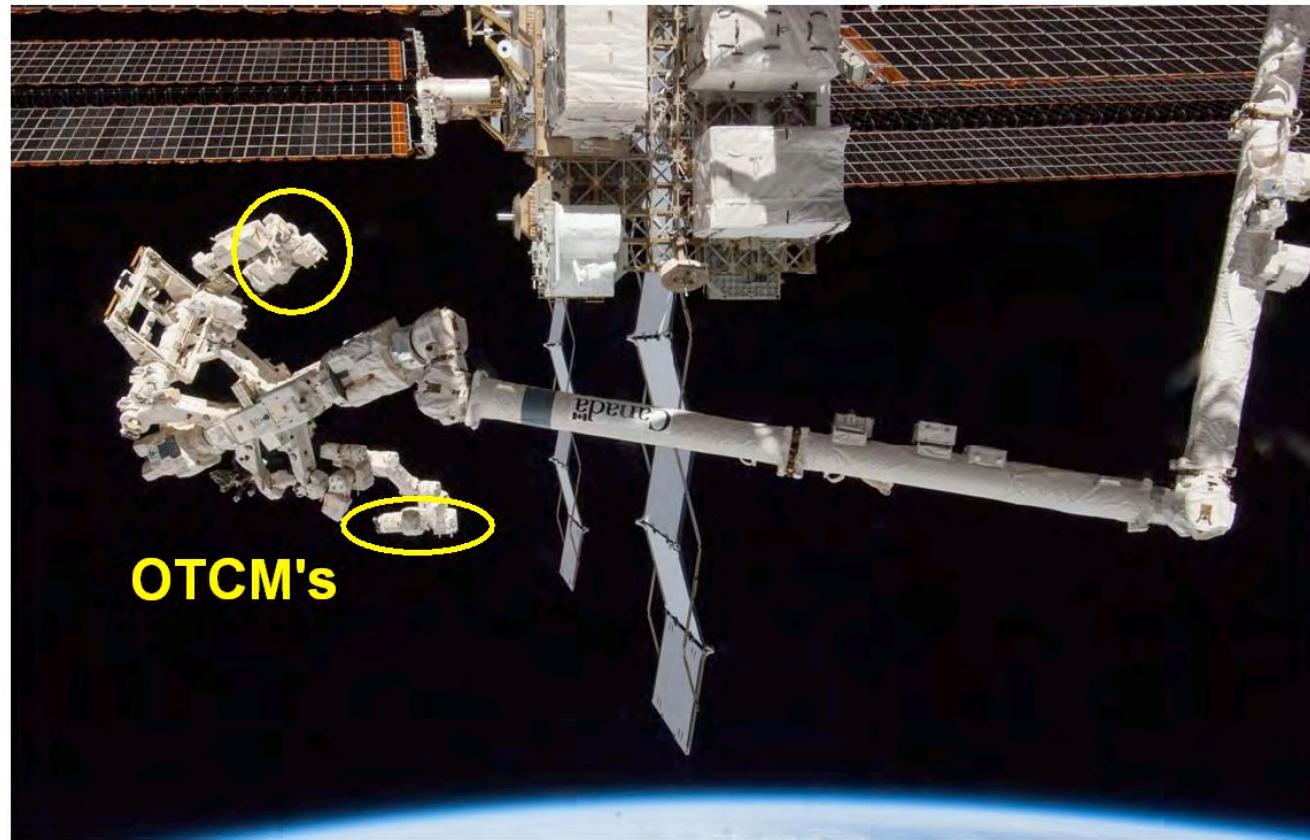




Detail of the ISS Robot Arm



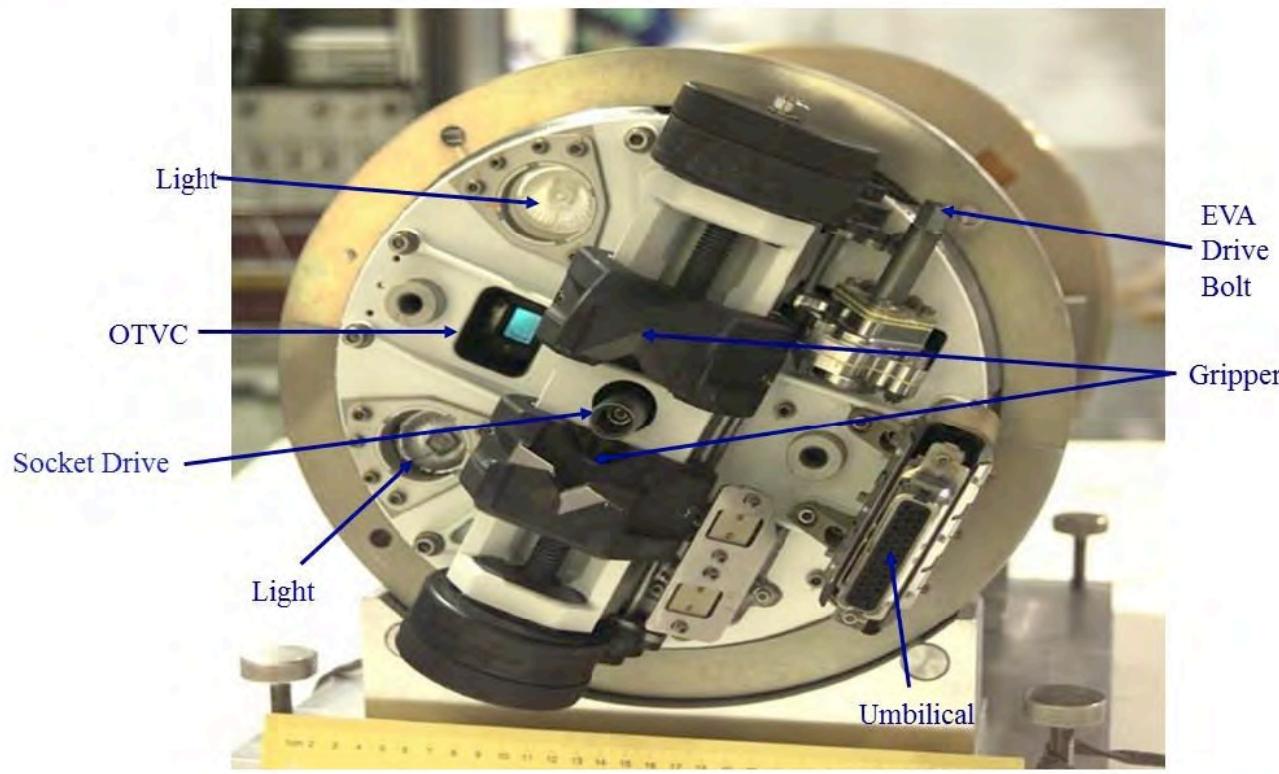
SSRMS with SPDM



OTCM: Our connection to the Space Station



ORU Tool Change-out Mechanism (OTCM)

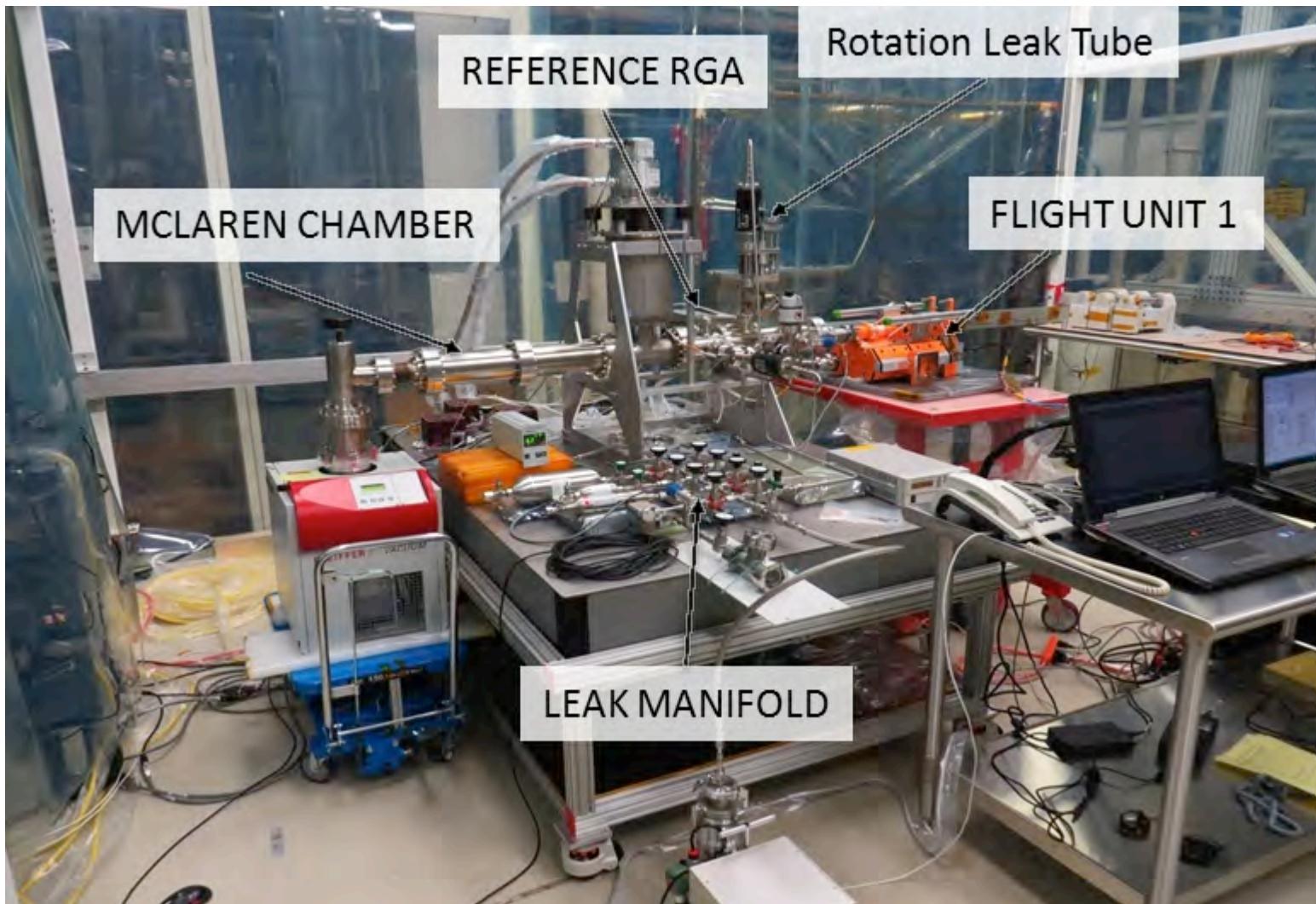




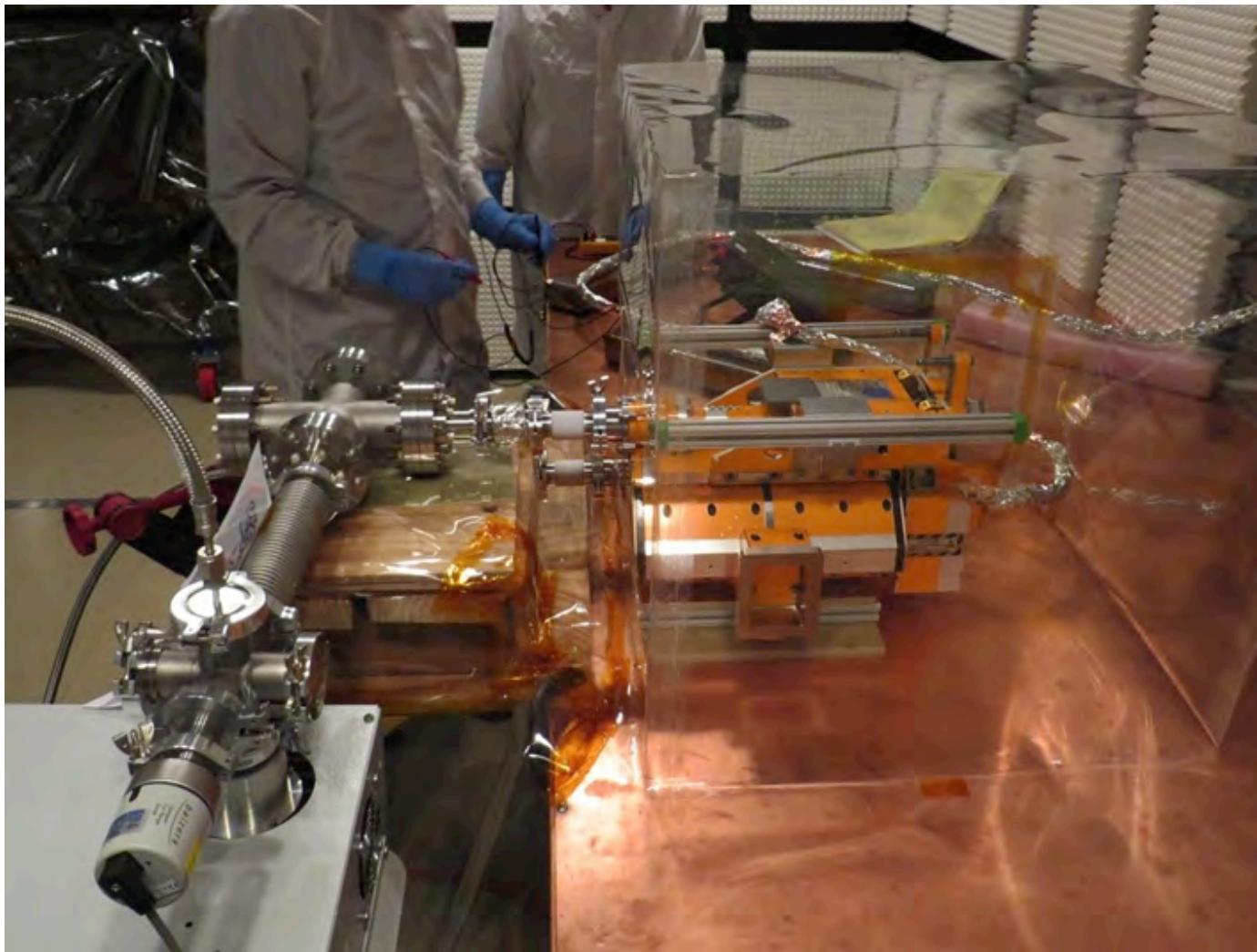
TESTING: Is it flight worthy?

- Incoming testing (did it survive shipping?)
- Comprehensive performance tests, before and after:
 - EMI emission and susceptibility testing
 - Vibration testing (launch simulation)
 - Thermovac testing
 - test plan managed by D. Rossetti
- Fit test
 - does it clear the JEM airlock?
 - prototype brought to Japan for physical fit check
 - *Cannot have **that** surprise on orbit!*

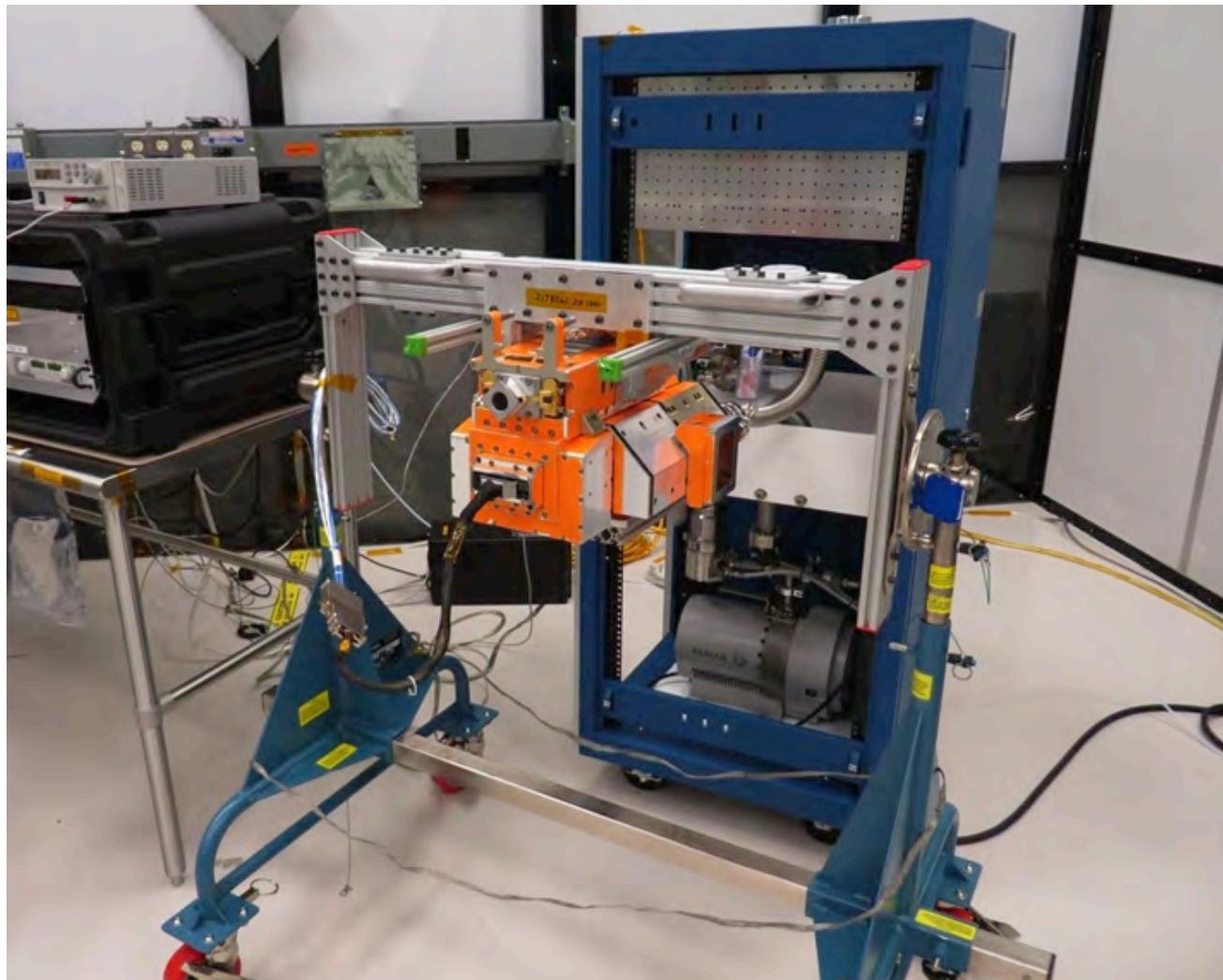
Comprehensive Performance Test setup



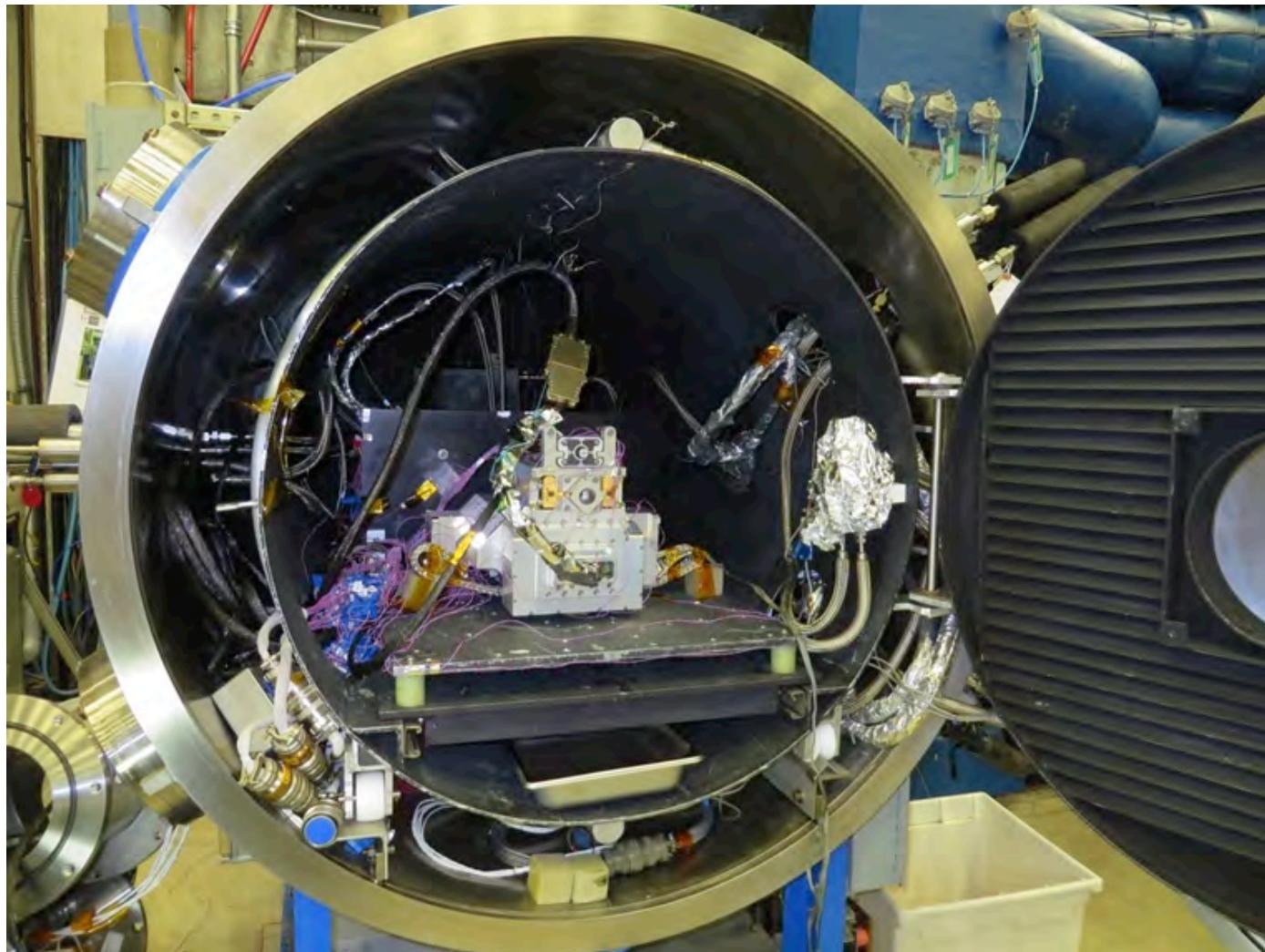
Flight Unit 1 in the EMI chamber



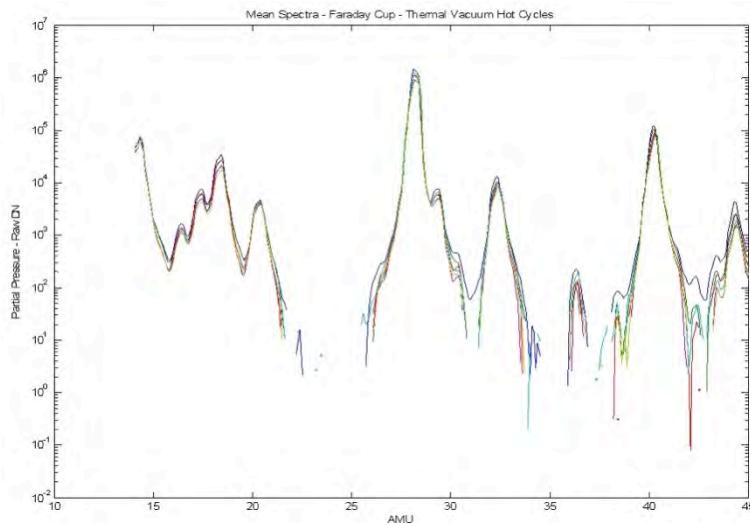
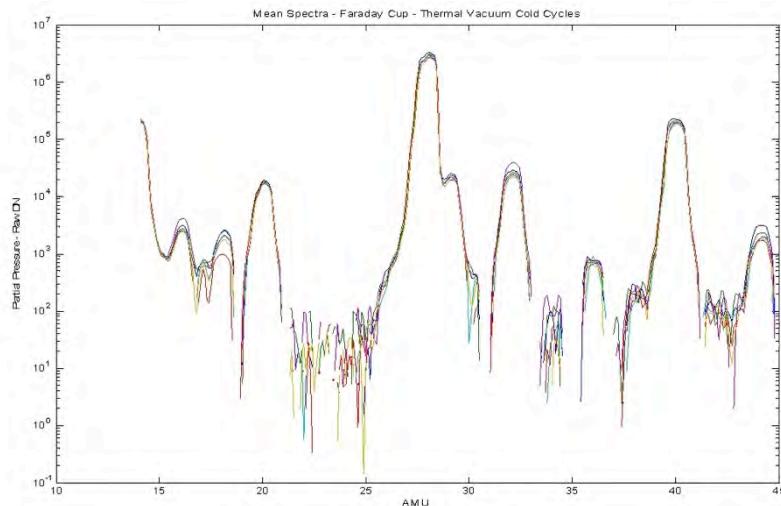
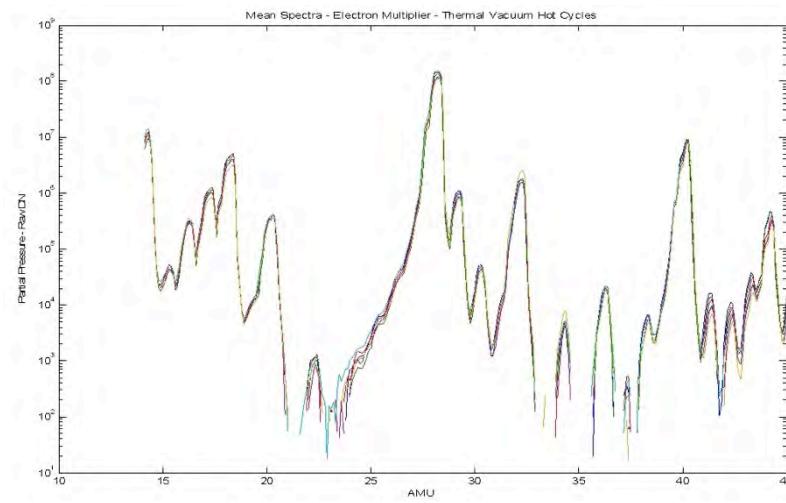
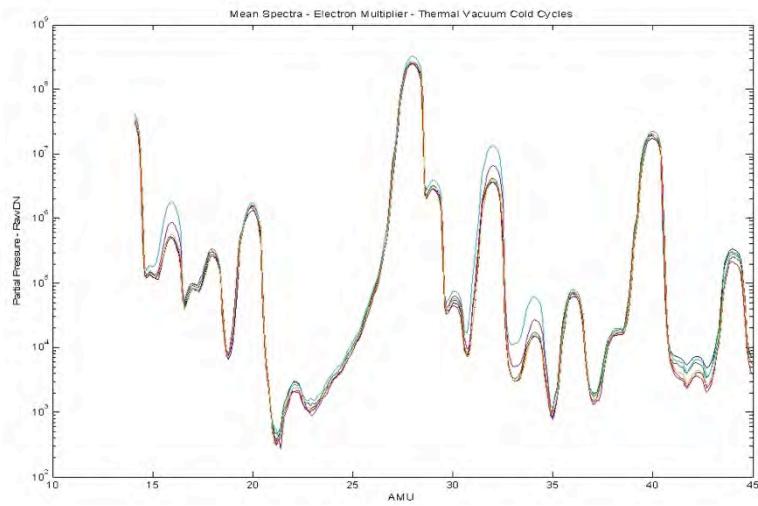
Flight Unit 1 on test dolly before Vibration test



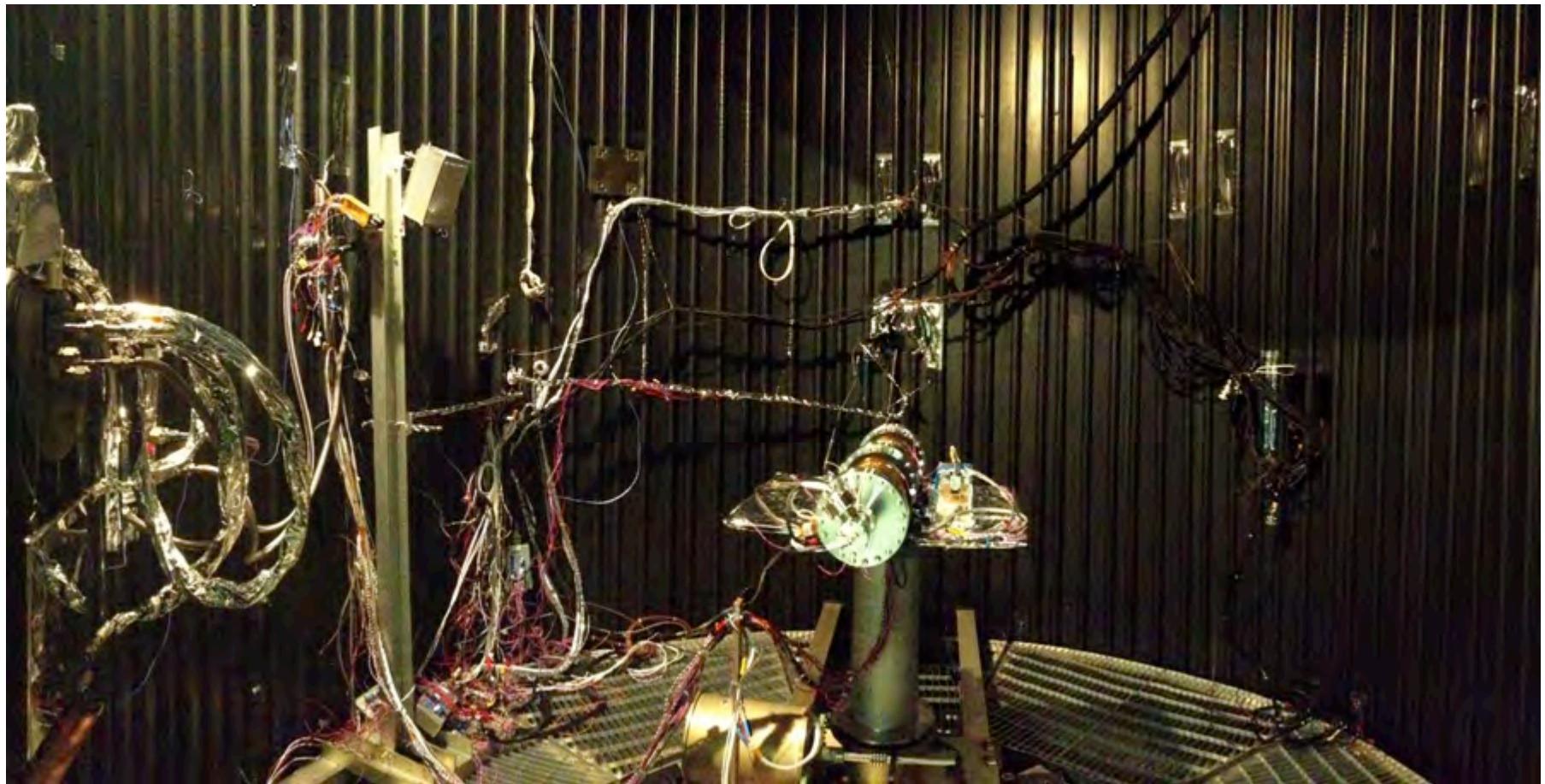
Flight Unit 1 inside the thermovac chamber



TV test data



RGA unit inside large test chamber



Aside: what does the RGA *actually* measure?



Outline



- What does an RGA measure: pressure, density, molecular flux?
- Attempt to quantify various aspects of ISS NH₃ leak detection using an RGA
 - Produce contour maps of free expansion
 - Plume model
 - Effusive ($M = 0$) response
 - Sonic orifice ($M = 1$) constraint
 - RGA response in this environment
 - Account for instrument location, orientation

Aside, cont'd: Model Assumptions



NH₃ Leak Cases



- Assumed mass loss rates of 15.9 lb_m/yr
 - Channel 2B PVTCS Leak Status & Troubleshooting Planning presentation package, 10/2/12
- Computed mass flux contour maps using Excel spreadsheets
- Assumed two different source configurations
 - $M = 0$ (effusion)
 - $M = 1$ (sonic orifice)
- Used Hertz-Knudsen equation to relate mass flux to RGA pressure similar to arrangement used in TV chamber configuration
 - This is not precisely the true pressure (normal momentum flux), but is consistent with how RGA readings are interpreted

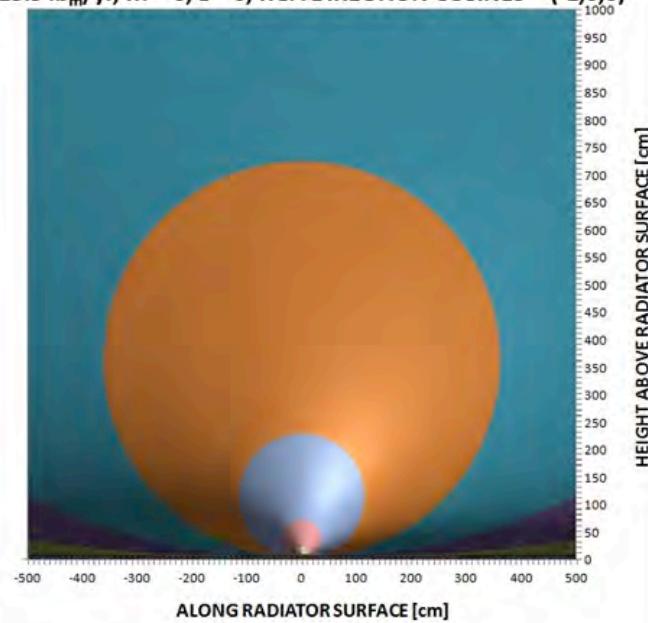
Plume flux expressed as RGA pressures



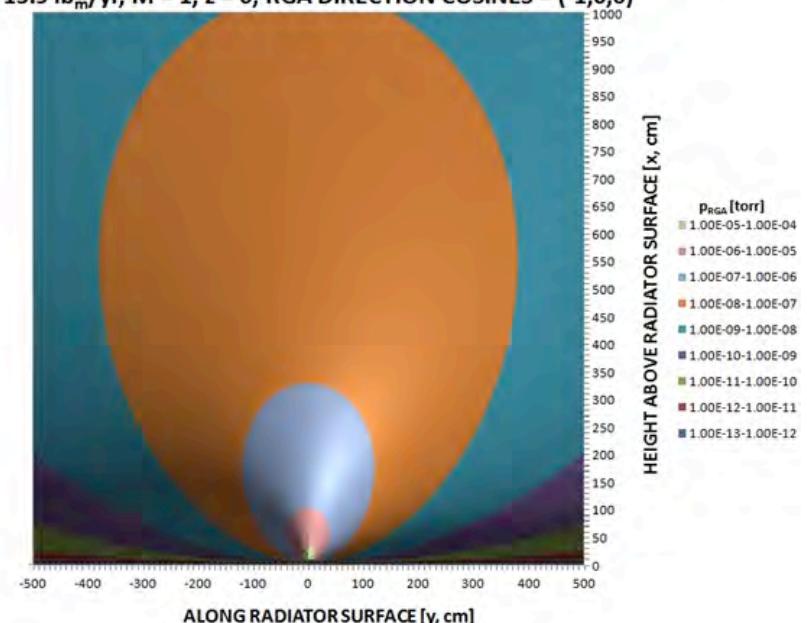
NH₃ Leak—RGA Facing Surface



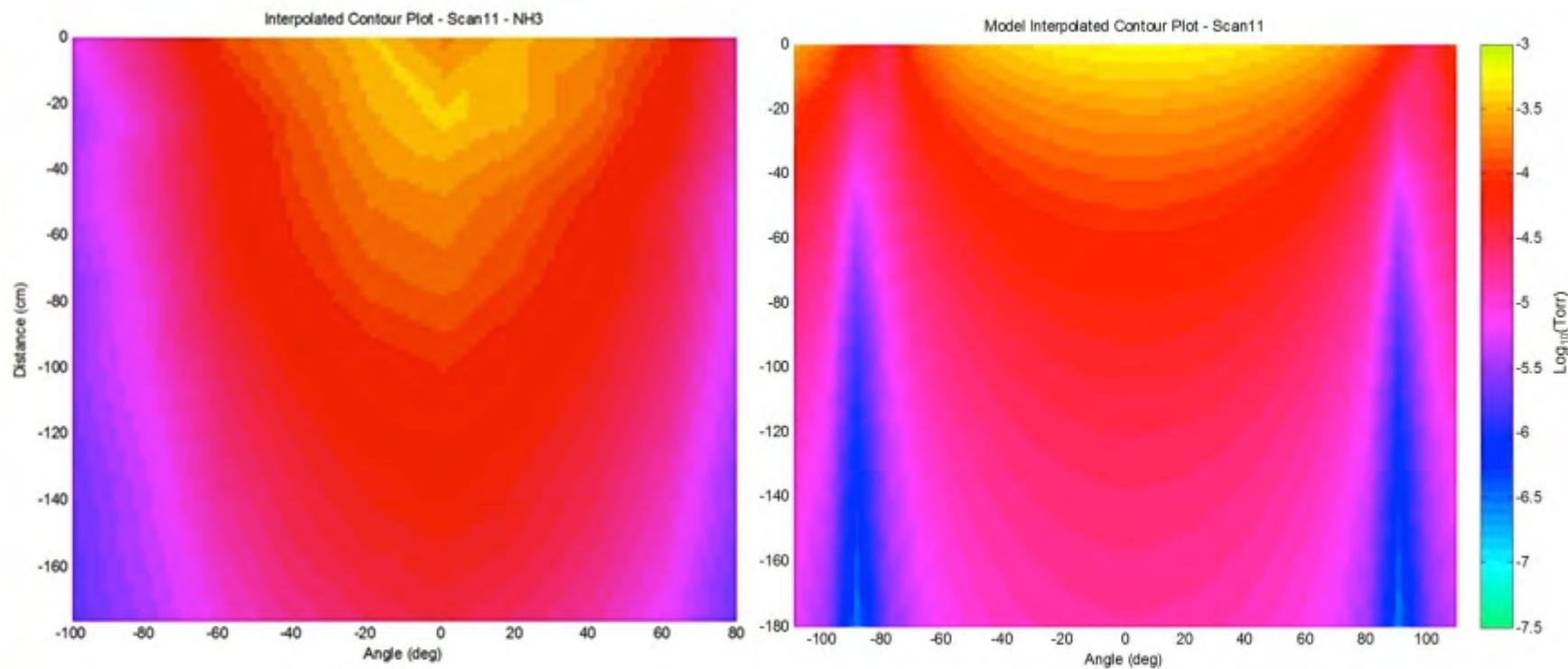
ISS NH₃ LEAK—RGA PRESSURE CONTOURS, HERTZ-KNUDSEN EQN.
15.9 lb_m/yr, M = 0, z = 0, RGA DIRECTION COSINES = (-1,0,0)



ISS NH₃ LEAK—RGA PRESSURE CONTOURS, HERTZ-KNUDSEN EQN.
15.9 lb_m/yr, M = 1, z = 0, RGA DIRECTION COSINES = (-1,0,0)



Response to simulated ISS leak



data from D. Rossetti, model by M. Worowicz

Flight Unit 1 delivered, ready for launch on ORB-3



Sunrise on launch day, October 28, 2014





Launch failure



The day after (surprisingly little damage)

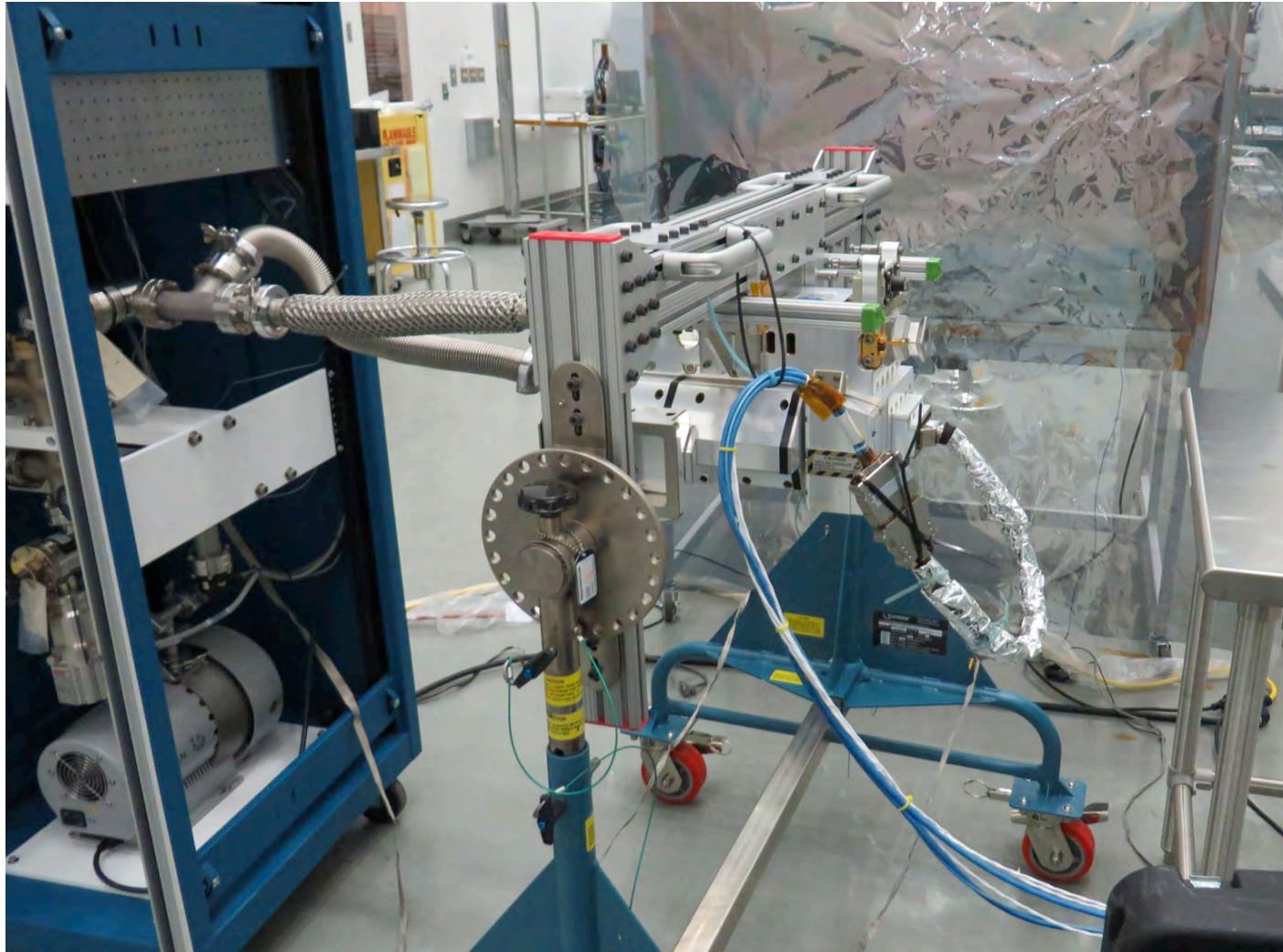


Post launch-failure: Flight Unit 2



- Fortunately, NASA/GSFC built a full spare of the flight package
- Selected a second RGA candidate for installation
- Work on integrating Flight Unit 2 began in December 2014
- Final tests finished mid-February, 2015
- Ready for launch, probably by end of 2015

Flight Unit 2 during testing





What comes next

- Launch delivers the instrument to the ISS
- Store on-board until operation scheduled
- Bring instrument outside through JEM airlock
- Grapple with main robotic arm
- *Take the unit for a test drive:*
 - assess different leak locating strategies
 - evaluate backgrounds
 - co-moving with station
 - ambient atmosphere (ram and wake effects?)



Lessons Learned

- Clear division of responsibilities
- Good communications
 - weekly telephone conferences during active times
- Think hard about deviations from pure COTS
 - high-stakes application requires flexibility
 - easy changes (for interfacing) help speed the project
 - go carefully with bigger changes
 - beware of unintended consequences
- Test, Test, and Test
 - realistic simulations are the best
- Build spares!